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Citation style: Sołtys-Lelek Anna, Barabasz-Krasny Beata, Różkowski Jacek. (2014). Participation of various habitat groups in the flora of spring niches in the Ojców National Park (Southern Poland). "Biodiversity Research and Conservation" (Vol. 36, (2014), s. 37-51), doi 10.2478/biorc-2014-0012



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Participation of various habitat groups in the flora of spring niches in the Ojców National Park (Southern Poland)

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Abstract: The paper presents composition of vascular plant species in spring niches in the Ojców National Park (Southern Poland). 111 species of vascular plants, fourteen mosses, two liverworts and one species of ferns were recorded during the first comprehensive study carried out in 2009 and 2010. Plants occurring in these places showed different degrees of association with spring niches. The largest group was represented by accidental krenophytes (74 species), while spring plants – obligatory krenophytes, constituted only a small part of the local flora (5 species). Meadow species of the *Molinio-Arrhenatheretea* class and forest species of the *Quercio-Fagetea* class, penetrating niche areas from the adjacent areas, were the dominating ones. Plants of aquatic and spring communities were scarce, due to the predominance of small type karst springs. The diversity of vegetation was significantly influenced by habitat factors such as availability of light, humidity or the amount of organic matter in the soil.

Key words: flora of spring fens, niche sources, various habitat groups of species, Ojców National Park, Poland

1. Introduction

Springs are one of the most valuable elements of the karst landscape of the Ojców National Park (ONP). Due to the small area of spring zones in the ONP, the habitats are poorly recognised. No comprehensive studies concerning the floristic structure of spring niches and their character have been carried out. Fragmentary data on spring plants are scattered among works on general flora in the ONP (Michalik 1978), aquatic habitats of Prądnik and Saspówka streams and some spring fens (Siedlecka-Binder 1967; Medwecka-Kornaś & Hawro 1993; Sołtys 2005).

Unfortunately, many spring niches in the area have been permanently altered by man, and the degree of those changes is quite varied – from casing, through permanent curbing and deepening. These activities have a huge impact on vascular plants, while common bryophytes easily re-colonize transformed habitats, growing on concrete circles or other constructions.

When natural flora components of spring areas are eliminated by anthropogenic activity, an important role in re-colonization is played by adjacent areas of spring niches which supply propagules of various species.

The main goal of the work was to analyse the floral structure of spring niches in the ONP, determine the share of species of different groups of the habitat in the flora and to indicate the most important factors affecting species variability. The studies will also help to illustrate the degree of transformation of spring niches.

2. Location and hydrogeological characteristics of the analysed spring niches

2.1. Description of the study area

The Ojców National Park (ONP) is located in southern Poland, 22 km north-west from Kraków (φ 50°12'N, λ 19°49'E) (Fig. 1). The ONP is a part of the Kraków-Częstochowa Upland macro-region – the

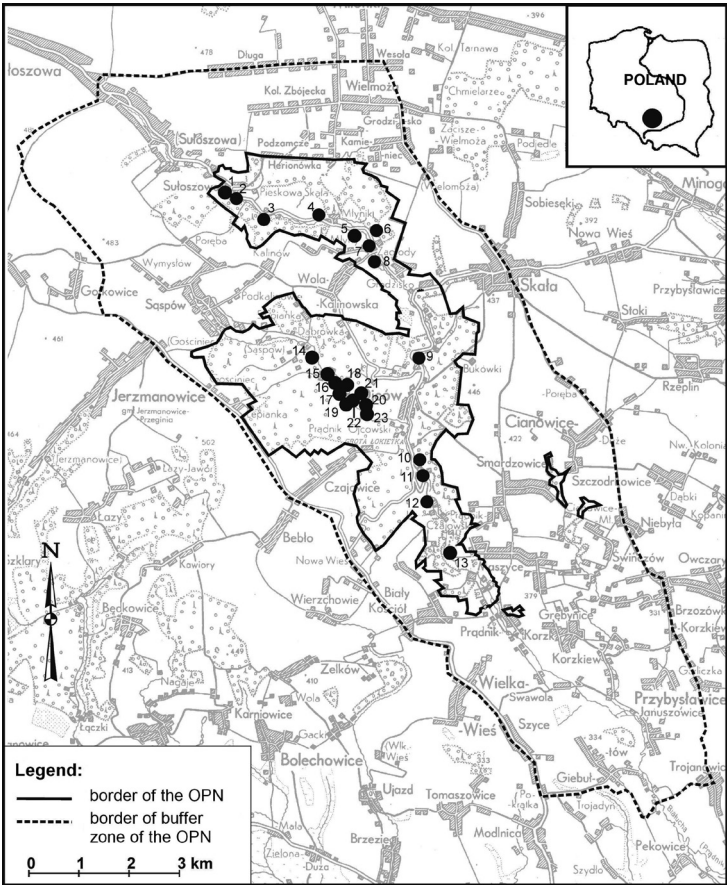


Fig. 1. Localization of the studied spring niches in the Ojców National Park (Southern Poland)

largest karst region in Poland. It covers the area of 2146 ha and together with the buffer zone – 6777 ha. The middle part of the Prądnik Valley (12 km long, Fig.

2), the middle and the lower parts of the Saspowska Valley (5 km long) and adjacent areas of the Jurassic plateau are within the park area. The highest parts of



Fig. 2. View of the Prądnik Valley in the Ojców National Park (photograph by R. Cieřlik)



Fig. 3. Outflow of one of the forest springs in the Ojców National Park; the dominant species associated with this spring is *Berula erecta* (Huds.) Coville (photograph by A. Sołtys-Lelek)

the area reach the altitude of 481 m a.s.l. and the lowest ones are – 285 m a.s.l. The geological bed is built of Upper Jurassic limestone whose thickness extends up to 200 m (Partyka & Kłasa 2008).

Strongly varied relief, exposure and denivelation all influence the microclimatic conditions occurring in the ONP which shows characteristic features of mountain climate. Mean precipitation varies from 748 to 773 mm per year (Brzeźniak & Partyka 2008). The area of the Park belongs to the zone of moderate warm climate where the average temperature of the year varies from +6 to +8°C and the average annual temperature range is 20.5°C. Occurrence of thermal inversions conducive to intensive cooling of the bottom of valleys, especially in autumn, is a common phenomenon there. The growing season lasts 203 days in the ONP. The vegetation is characterized by a mosaic arrangement of communities. About 72% of the Park is covered by forest communities, 22% by meadows, pastures, xerothermic grasslands and arable lands and 1% – by water courses (Partyka & Kłasa 2008).

2.2. Characteristics of the spring niches

Fissured-karst-porous Upper Jurassic aquifer is the main groundwater basin there. It is an uncovered type basin which is mainly drained by local and intermediate flow systems formed by a varied relief, especially deeply cut valleys of the Prądnik and Sąsówka streams. Underground runoff within the Upper Jurassic aquifer in the Prądnik catchment basin is formed mainly as a result of effective infiltration of precipitation (Rózkowski *et al.* 2001). In 2008-2009, 49 active zones of spring niches, among them 23 zones with a natural outflow, were inventoried in the ONP and its buffer zone (Fig.

3). The springs draining the Upper Jurassic aquifer comprise mainly descending springs (subordinately ascending) as well as under-slope and near-channel ones. The discharge of 80% of springs is in the range of 0.1-10 dm³/s. The main directions of spring exposures, referring to the tectonics of the rock massive, are as follows: N, NE, SE, SW and NE, only 7 niches have SW and SSW exposures (Fig. 4). Due to the nature of recharge and drainage, there are mainly descending, under-slope and near-channel springs in the area. According to the hydrobiological criterion, horizontal drainage is carried on through karst springs, the ones with spot water outflow. Fens represent karst springs (Sołtys-Lelek *et al.* 2010).

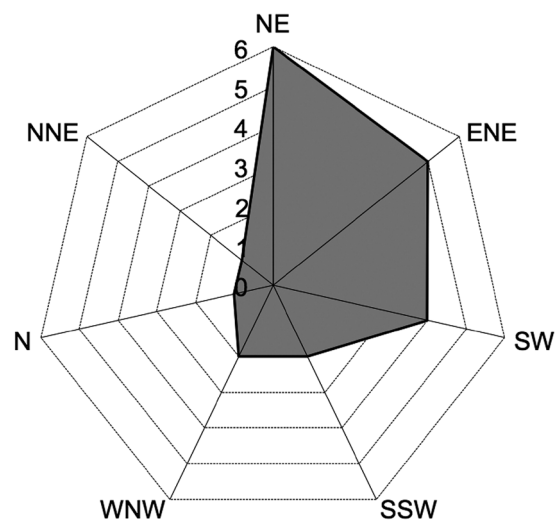


Fig. 4. Exposure of the spring niches investigated in the Ojców National Park

Waters of the Upper Jurassic level form a shallow flow system in the environment of carbonate rocks. Those are two ionic HCO_3 -Ca waters, with 200-400 mg/dm³ mineralization and dominant carbonate hardness, medium hard (T_H 190-340 mg CaCO_3 /dm³). The range of concentrations of macro and secondary components in the waters (mg/dm³) is as follows: Ca 70-135; Mg 0.1-11.3; Na 2-14; K 0.5-13; HCO_3 205-310; SO_4 0.3-76; Cl 4-28; NO_3 5-45; PO_4 0.1-3; SiO_2 6.5-13.5. Calculated values of SI_{calc} saturation (from -0.45 to +0.22) prove a state close to the balance of calcite in groundwater, which is characteristic for a scattered flow system, in turn the result of dissolution of carbonate rocks by acidic precipitation. Water temperature is usually 7.610°C and it is close to the average temperature of water and air. These are freshwaters (PEW within the range 270-720 $\mu\text{S}/\text{cm}$), neutral or slightly alkaline (pH 7.0-7.5), with oxygen content typical for groundwaters (O_2 6.8-11.0 mg/dm³), representing poorly oxidizing redox conditions (Eh 330-530 mV) (Rózkowski 2006).

3. Material and methods

It was assumed, for the purpose of the study, that a niche is an outflow spring with the adjacent surroundings of the outflow. 21 spring niches occurring within the ONP boundaries were chosen for the investigation (13 in the Prądnik Valley, 8 in the Sąspowska Valley) and two spring fens in the Sąspowska Valley (Fig. 1). Near-channel and channel springs without spring niches were skipped. Plants occurring within spring niches (in eukrenal and hypokrenal zones) and in slopes of spring niches were recorded in the vegetation seasons of 2009 and 2010 and their quantitative participation was also determined by the Braun-Blanquet scale. During the study, the areas of the niches were measured and percentage of their damage was estimated. Floristic fieldworks were supplemented with archival data from Siedlecka-Binder (1967) and Soltys (2005).

Syntaxonomic membership of each species was presented on the overall list. It enabled the author to assign most of the plants to the following habitat groups: springs (the *Montio-Cardaminetea* class according to Wolejko 2000; Górski 2007; Matuszkiewicz 2007; Kliment *et al.* 2008; Krause & Wika 2009; Osadowski *et al.* 2009; Catteau *et al.* 2010; Parusel *et al.* 2012), reeds (the *Phragmitetea* classes according to Herlich 1981; Matuszkiewicz 2007; Osadowski 2010; Scheuzerio-*Caricetea nigrae* according to Matuszkiewicz 2007), meadows (the *Molinio-Arrhenatheretea* class), shrubs (*Epilobietea angustifolii*, *Rhamno-Prunetea* classes) forests (*Quercu-Fagetea*, *Vaccinio-Piceetea* classes) and ruderal (*Artemisietea vulgaris*, *Stellarietea mediae* classes) according to Matuszkiewicz 2007. The group “others” included species which showed lack

of association to any of the above-mentioned habitat groups.

Division of spring plants according to their habitat requirements was adopted after Kucharski (2007), in a modified version. Obligatory krenophytes (KO) – plants occurring only in spring areas, facultative krenophytes (KF) – plants that find optimum development conditions in the areas of spring, but that may occur also outside them. The group includes hydrophytes and species associated with riparian and coastal habitats of still and flowing surface waters, indifferent krenophytes (KI) – species accepting the conditions of spring zones but having optimum conditions outside them. They are associated with variably moist, moist and wet habitats and flood meadows. They also include indicator species of extremely wet soils, accidental krenophytes (KA) – plants that avoid spring zones, however, sometimes “transferred” there from adjacent habitats.

DCA analysis (Hill & Gauch 1980) was carried out to investigate which of the selected variables characterising spring zones exerted the most considerable impact on varied floristic content of spring niches. For the purpose of the analysis and considering the immediate vicinity, the niches were divided into the following categories: meadows, tall humid vegetation on alluvial sediments, thicket, forest. Ecological indicator numbers were used to characterise habitats (according to Zarzycki *et al.* 2002): L – light, H – organic matter content, W – soil moisture, Tr – trophic, K – continentality, R – soil (water) acidity (pH), T – temperature. The analysis was carried out on the basis of species contents in particular niches and quantitative participation of species in niches determined by the Braun-Blanquet scale and applying CANOCO programme, version 3.12 (Ter Braak 1991).

The applied nomenclature of vascular plants, ferns and taxonomic membership were adopted from the one used in the study of Mirek *et al.* (2002), mosses and their taxonomic membership were taken after Ochrya *et al.* (2003) and liverworts – after Grolle & Long (2000). The applied syntaxonomic nomenclature was taken after Matuszkiewicz (2007).

4. Results

4.1. Characteristics of the flora of the spring niches

111 species of vascular plants, fourteen mosses, two liverworts and one species of ferns were found in the spring niches in the Ojców National Park. The following data are presented for each species: the habitat it belongs to, adopted on the basis of phytosociological classification; membership in the plants of spring zones, according to the habitat classification by Kucharski (2007); the numbers of spring niches or spring fens according to the Fig. 1 – given in brackets and citations from literature. Explanations of abbreviations can be

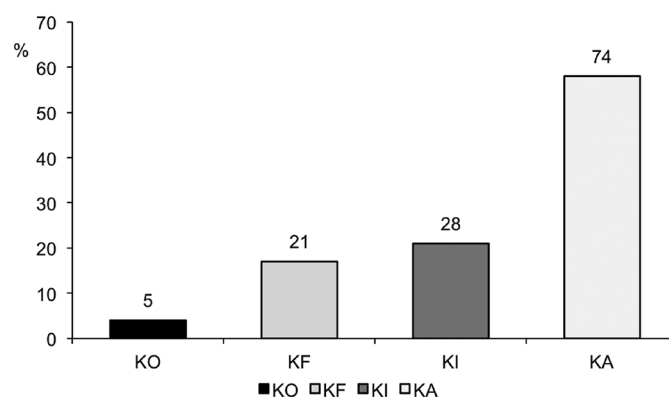


Fig. 5. Comparison of participation of spring-associated plants according to their habitat category
 Explanations: KO – krenophytes obligatory, KF – k. facultative, KI – k. indifferent, KA – k. accidental

found in the part describing methodology of the work. List of species is in the Appendix 1.

The following plants occurred most frequently in spring niches in the ONP: *Ranunculus repens* (15 niches), *Cirsium oleraceum* (14), *Urtica dioica* (13), *Aegopodium podagraria*, *Cratoneuron filicinum* (12 niches each), *Chrysosplenium alternifolium*, *Lysimachia nummularia*, *Mentha longifolia*, *Myosotis palustris* (11 niches each), *Rumex obtusifolius* (10), *Brachythecium*

rivulare, *Chaerophyllum hirsutum*, *Geum urbanum* (9 niches each) and *Chaerophyllum aromaticum* (8). As many as 92 species found there occurred sporadically as they were recorded in 1-3 spring niches only. They represented various syntaxonomic groups. There were also a few protected plants listed under strict protection – *Aconitum moldavicum* and *Epipactis helleborine* – and partly protected – *Asarum europaeum*, *Hedera helix* and *Primula elatior*.

Table 1. Comparison of the percentage of spring niches damage in the ONP considering their size and the number of species inhabiting each niche and its neighbourhood

Number of niche in the study area	Neighbourhood	Damage of niche [%]	Area of niche [m ²]	Number of species
1	F	0	1.89	11
2	F	100	1.00	6
3	M	95	1.00	16
4	T	20	8.00	18
5	P-h	0	0.50	11
6	M	0	5.20	23
7	M	90	8.10	15
8	P-h	95	0.60	11
9	P-h	95	1.50	12
10	P-h	95	2.00	11
11	M	80	0.75	14
12	M	50	2.00	24
13	T	0	1.75	23
14	F	0	9.00	15
15	F	0	12.50	19
16	F	0	3.75	11
17	F	5	12.00	14
18	T	10	4.00	14
19	F	0	1.05	11
20	T	0	12.00	34
21	M	0	16.00	11
22	M	0	25.00	28
23	M	0	25.00	38

Explanations: F – forest, M – meadow, P-h – tall humid vegetation on alluvial sediments, T – thicket

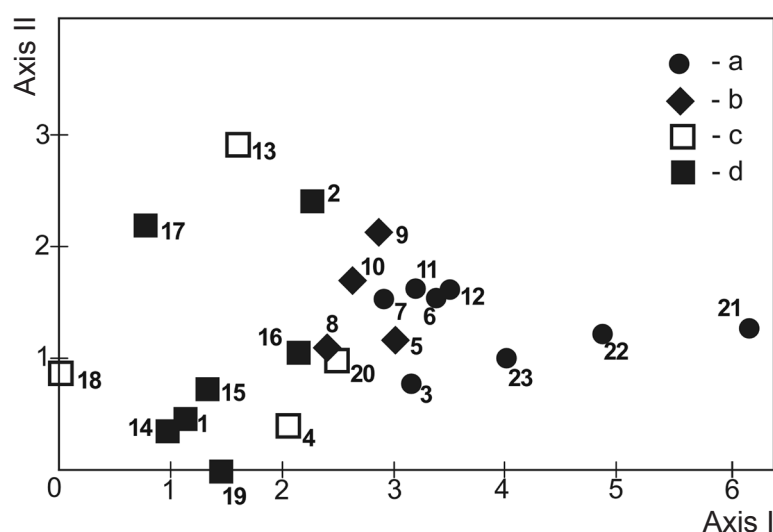
Table 2. Values of the Pearson's correlation (r) between DCA axes and some characteristic features of the studied spring niches in the Ojców National Park

Characteristics	Correlation values			
	Quality		Quantity	
	Axis I	Axis II	Axis I	Axis II
Zarzycki indicators:				
L – light value	0.81	-0.03	0.87	0.02
H – organic matter content value	0.76	0.21	0.73	-0.21
W – soil moisture value	0.79	0.01	0.68	-0.19
Tr – trophy value	0.12	-0.26	0.13	0.17
K – continentality value	-0.10	-0.34	-0.11	-0.19
R – soil (water) acidity (pH) value	-0.24	-0.14	-0.12	0.03
T – temperature value	-0.21	0.24	-0.16	-0.07
KO – krenophytes obligatory	0.03	0.19	0.26	0.06
KF – krenophytes facultative	0.61	0.28	0.55	-0.13
KI – krenophytes indifferent	0.52	-0.05	0.65	0.05
KA – krenophytes accidental	0.04	-0.05	0.20	0.06
Exposition	0.05	-0.01	0.08	-0.14
Damage of niche	0.24	-0.26	0.42	-0.07
Area of niche	0.03	0.43	0.02	0.36
Number of species in a niche	0.36	0.03	0.50	0.04

The largest habitat group in the niches was represented by meadow species of the *Molino-Arrhenatheretea* class (37 species); within the group – 17 species of the *Molinietalia caerulae* order were associated with variable moist, moist or wet meadows. The second largest group comprised 26 species of forest plants of the *Querco-Fagetetea* class. Among them, special attention should be paid to the species associated with riparian marshes – *Alno-Ulmion*. The flora of communities of the *Scheuchzerio-Caricetea nigrae* class in poor fens and fens and of the *Phragmitetea* class in reed beds comprised 11 species altogether. There were also a few representatives of the *Montio-Cardaminetea*

class which included plants occurring in specific conditions of seepage spring areas. Six species represented bryophytes: *Brachythecium rivulare*, *Conocephalum conicum*, *Cratoneuron filicinum*, *Pellia epiphylla*, *Plagiothecium laetum*, *Rhizomnium punctatum* and three – vascular plants: *Cardamine amara*, *Chrysosplenium alternifolium*, *Impatiens noli-tangere*. Investigation of the seepage spring areas proved also the occurrence of nitrophilous species belonging to the *Artemisietea vulgaris*, *Stellarietea mediae* and *Epilobietea angustifolii* class – 19 species altogether (Appendix 1).

Among plants of spring fens with different habitat requirements, obligatory krenophytes comprised only

**Fig. 6.** Ordination of spring niches in the Ojców National Park along the first two DCA axes. based on species composition; division of spring niches considering their immediate vicinity

Explanations: a – meadow, b – tall humid vegetation on alluvial sediments, c – thicket, d – forest

4% of them (one moss, one liverwort and three vascular plants), facultative krenophytes comprised 17% (four mosses and 17 vascular plants), indifferent krenophytes comprised 21% of them (three mosses, one liverwort and 24 vascular plants) and accidental krenophytes comprised 58% (six mosses – mostly forest ones, one species of ferns and 67 vascular plants, Fig. 5).

Small niches, with areas smaller than 10 m² (17 of 23 niches) were found to occur most commonly in the ONP (Table 1). Almost half of the niches – 11 showed signs of damage and up to 8 revealed damage of the surface exceeding 50%. The niches richest in species occurred near meadows (15-38 species) and shrubs (14-34 species), the abundance was the result of transfer of species associated with the habitats.

DCA analysis carried out to verify which of the selected variables characterizing spring fens exerted

the greatest impact on the diversity of their floristic composition showed that the following factors played important roles: availability of light, organic matter content, moisture content which resulted in the occurrence of facultative and indifferent krenophytes, and the number of species in the niche (Table 2). The niche area and the degree of its damage showed lower correlation.

Graphic presentation of the relationships based on species contents showed ordering of the niches along the DCA axis I – from forest-shrubs with a small amount of facultative and indifferent krenophytes, with lower light availability, organic matter content and moisture (left side of the graph) to meadow niches with a large share of the above-mentioned two types of krenophytes, with higher availability of light, moisture and organic matter content (right side of the graph). The surface of niches was the only factor weakly correlated with the axis II (Fig. 6, Table 2).

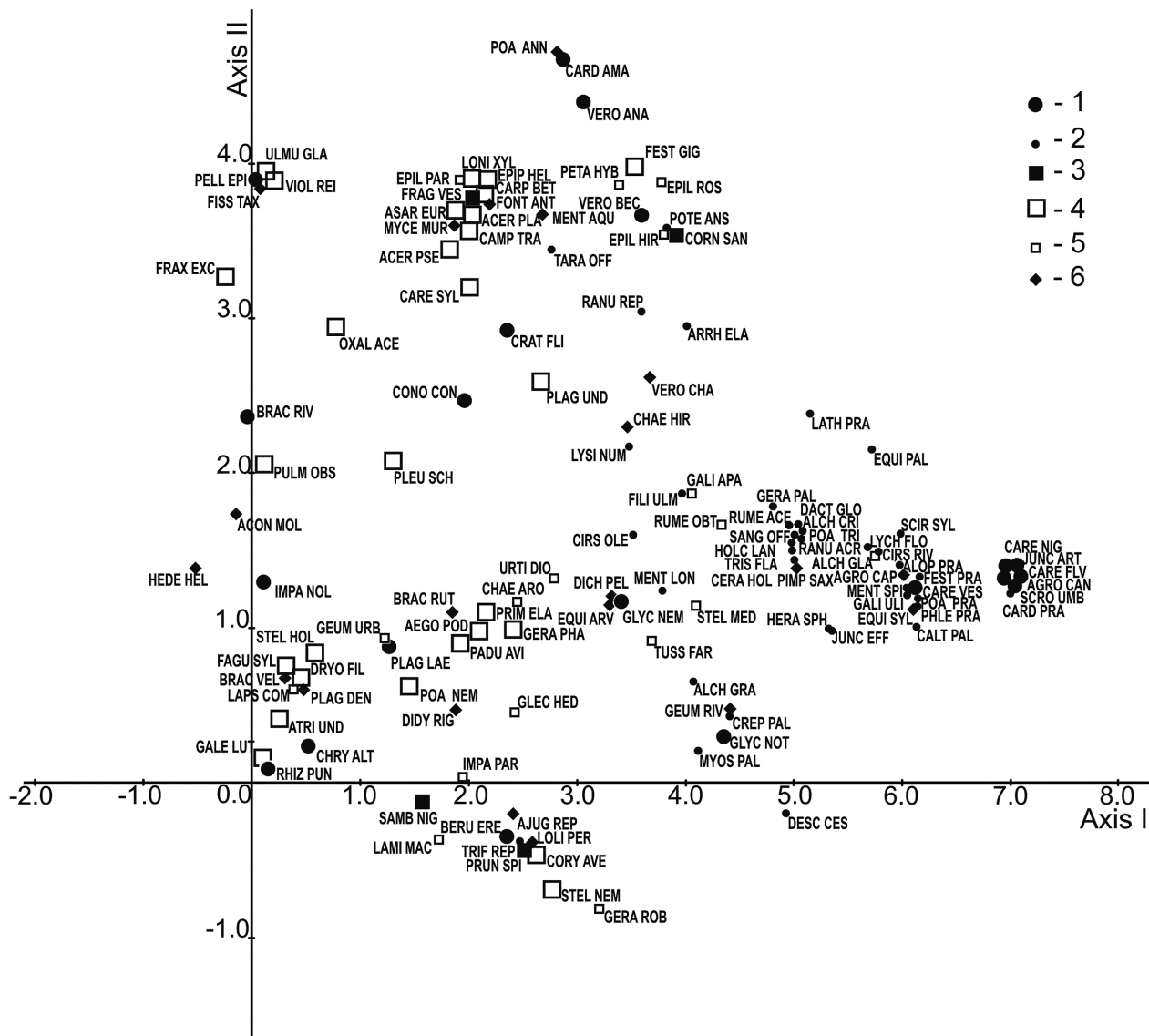


Fig. 7. Ordination of species of spring niches in the Ojców National Park along the first two DCA axes, based on their quantitative participation. Explanations: 1 – Classes *Montio-Cardaminetea*, *Scheuchzerio-Caricetea nigrae*, *Phragmitetea*, 2 – Orders *Trifolio fragiferarum-Agrostietalia stoloniferae*, *Molinietalia coeruleae*, *Arrhenatheretalia* and Class *Molinio-Arrhenatheretea*, 3 – Classes *Epilobietea angustifolii* and *Rhamno-Prunetea*, 4 – Alliance *Alno-Ulmion*, Classes *Quercio-Fagetea* and *Vaccinio-Piceetea*, 5 – Classes *Artemisietea vulgaris* and *Stellarietalia mediae*, 6 – other habitats (with different humidity)

Table 3. Participation of different habitat groups of species in the flora of spring niches in the Ojców National Park

Habitat groups of species	Number of species	Participation in the flora of the niches [%]
<i>Montio-Cardaminetea</i> (spring fens and places, where arrears snow)	9	7
<i>Scheuzerio-Caricetea nigrae</i> (poor fens and fens)	4	3
<i>Phragmitetea</i> (rushes, reeds)	7	5
<i>Trifolio fragiferae-Agrostietalia stoloniferae</i> (floodplain grasslands)	3	2
<i>Molinietalia coeruleae</i> (meadows constantly and periodically wet)	17	13
<i>Arrhenatheretalia</i> (fresh meadows and pastures)	7	5
<i>Molinio-Arrhenatheretea</i> (fresh and moist meadows - joint species)	10	8
<i>Epilobietea angustifolii</i> (nitrophilous clippings and ruderal places)	2	2
<i>Rhamno-Prunetea</i> (thermophilous thickets)	2	2
<i>Alno-Ulmion</i> (moist riparian forests)	5	4
<i>Quercu-Fagetea</i> (deciduous forests - different humidity)	21	17
<i>Vaccinio-Piceetea</i> (coniferous forests and woods - different humidity)	2	2
<i>Artemisietea vulgaris</i> (moist, ruderal and nitrophilous places)	14	11
<i>Stellarietea mediae</i> (weeds of cultivated fields and ruderal places)	3	2
Other habitats (different humidity)	22	17
Total	128	100

Ordering of species based on their quantitative share in niches along the DCA axis I showed that the existing plants could be grouped according to the habitat gradients – from the most shade-loving plants (of the *Quercu-Fagetea*, *Vaccinio-Piceetea* class) medium wet, with a lower content of organic matter, growing in niches poor in species (left side of the graph) to photophilous ones (of the *Scheuzerio-Caricetea nigrae*, *Phragmitetea*, *Molinio-Arrhenatheretea* class), wet, which liked relatively fertile soil, belonging to facultative and indifferent krenophytes, associated with niches with a large number of species (right side of the graph). In this case, the DCA axis II did not show any significant correlation (Fig. 7, Table 2).

5. Discussion

Springs are such ecosystems where groundwaters reach the surface of the ground or they get close to the surface, on land – atmosphere or land – water boundaries. Geomorphological conditions of springs enable functioning of many biological micro-environments and a wide range of plant and animal species. The impact on the occurrence and development of seepage spring areas and their rich biodiversity is a combination of the following factors: geological (ground lithology), hydrogeological (water circulation conditions, yield of discharges, water chemistry), geomorphological (types of springs, processes of erosion) and biocenotic (fauna and flora) (Szulc 1983; Allan 1998; Pazdur *et al.* 2002; Pentecost 2005; Osadowski 2010). A significant role is played by anthropogenic factors, taking into account development of the drainage area of springs

and the degree of its urbanization. In the opinion of many ecologists, drainage areas of springs are so called “ecological islands” having favourable conditions for the development of specialized organisms (Cantonati & Lange-Bertalot 2006; Osadowski 2010). They are also a refugium for protected and endangered species, including the ones of mountain and foothill character (Kucharski & Filipiak 1999; Szymczyk & Rahmonov 2010). Due to their high susceptibility to changes in environmental ecosystems, the areas were considered to be endangered not only in Poland but also in the entire continent (Kurowski *et al.* 2008).

The seepage spring areas occupy only approximately 0.015 hectares in the ONP. 111 species of vascular plants, representing 11% of the flora of the Park were found within that small area. Siedlecka-Binder (1967) had reported earlier only 12 vascular plants and 2 species of mosses in spring areas and 32 species of vascular plants, 6 bryophytes and 1 liverwort species in watercourses. Typical vegetation of seepage spring areas of the *Montio-Cardaminetea* class represents a small percentage – just 7% of the niche flora, despite natural conditions caused by specific water chemistry which favours its development (Rózkowski 2006). Currently identified species of vascular plants belong up to 11 syntaxonomic classes, among them the most numerous are: *Molino-Arrhenatheretea* and *Quercu-Fagetea* (Table 3). Similar proportions in the composition of vegetation in spring areas were earlier observed during the research of those types of habitats (Kucharski & Filipiak 1999; Kucharski 2007). Occurrence of representatives of the above-mentioned two classes was closely connected with the vicinity of springs – mostly

hay meadows – *Arrhenatheretum elatioris*, deciduous forests *Tilio-Carpinetum* and riparian forests with *Alno-Ulmion*. Hence, it can be stated that the immediate vicinity of spring niches was one of the most important factors influencing the flora of spring fens in the ONP. It mainly resulted from the fact that most of the spring fens were small karst springs easily penetrated by species from the neighbouring areas. It often led to transfer of plants atypical for the habitat (accidental krenophytes – Fig. 5), sometimes even ruderal, which were additionally favoured by a considerable degree of niche damage (Table 1). Ruderalisation phenomena of spring fen vegetation were observed, for example, by Czarnecka (2009) in some spring fens located at the edge zone of Roztocze (Eastern Poland). However, they mostly concerned spring fens covering large areas, where strong anthropopressure occurred.

The degree of damage of spring fen niches mainly refers to various forms of their reconstruction or outflow control regulated by mounting pipes or barriers raising water, placing open or closed concrete rings. Totally destroyed niches are completely reconstructed by covering them by a construction in the form of a concrete house or something like a well, where concrete casing covers the walls of the well and the outflow is covered as well – the so-called covered casing. Niches with no visible damages are natural ones, *i.e.* the ones with spring outflows with no visible signs of anthropogenic impact. In the period of 2008-2009, the ONP made an inventory of 32 active spring fen niches, including 3 secondary outflow intakes (Sołtys-Lelek *et al.* 2010). Only 16 springs of those had natural, non-transformed outflows. More than half of the spring fens chosen for the current studies had niches damaged to various degrees. Apart from that, most of them covered the area smaller than 3 m² and only four of them were larger than 10 m² (12-16 m²); the largest were seepage springs covering the area of approximately 25 m² (Table 1). Small size of niches caused that the degree of damage indirectly affected species content in the vegetation occurring there. Perhaps the degree of damage entailed occurrence of a small amount of typical spring species of the *Montio-Cardaminetea* class, which were sensitive to anthropogenic impact on their habitat and a relatively large share of ruderal species of *Stellarietea* and *Artemisietea* classes (Table 3). Despite the occurrence of a favourable habitat of carbonate rocks, occurrence of limestone spring fen communities *Cratoneurion commutati* was not corroborated within the area of the ONP. Although, *Cratoneuron filicinum* was confirmed in nearly half of the spring niches, other typical species for that relation were not found in the vicinity of springs. On the other hand, ruderal species occurred in the niches regardless of the neighbourhood, because they showed considerable tolerance to habitat

disturbance and disruption of the ecosystem natural balance of (Fig. 7, Table 2).

Habitat conditions constituted another very important factor influencing the floristic composition of spring fens in the ONP. As it was shown by the investigations, the most important environmental factors included: availability of light, humidity and the content of organic matter in the soil (Table 2, Figs. 6-7). Light indicator was the factor that had the biggest impact on the diversity of floristic composition in the niches. It exhibited the highest value of the correlation coefficient with the DCA axis I. Species living in moderate light and partial shadow ($L = 3-4$) were associated with open habitats such as meadows and reed habitats (Figs. 6-7 – the right side of the graph). They constituted the largest floristic group of the investigated niches. The second largest group in the niches comprised shade-loving species growing in places – from deep shadow through moderate shade to half-shade ($L = 1-2-3$). The species were associated with the forest-shrub niches (Figs. 6-7 – the left side of the graph). Other important habitat factors in case of spring fen plants also included moisture and organic matter content in the soil, as mentioned above. Hygrophytes and mesophytes comprised majority of species growing in spring niches. Especially, the first group was very sensitive to fluctuations in soil moisture. They tolerated fresh soil, but they grew best on damp and wet soils ($W = 3-4-5$). In terms of organic matter content, they tolerated mineral-humus and organogenic soils ($H = 2-3$) (Zarzycki *et al.* 2002).

Generally, the floristic composition of spring niches in the ONP was significantly altered due to small area of the niches and strong anthropopressure. However, there are still habitats in that area which shelter rare species of moisture-loving plants and animals. Therefore, they should be protected against further devastation by man, mostly occurring in meadow niches, which are often located within the limits of villages and easily accessible to the local population. An attempt should also be made, especially within the area of the Ojców National Park, to re-naturalise the altered spring areas. Work of this kind should include monitoring of botany, entomology and hydrology. First, the re-naturalization must cover the springs where fragmentary spring fens are still preserved and there is a chance to rebuild their typical flora and fauna. Such springs as the one “by the car park” in Pieskowa Skała (spring No 2) or “near the SOP station” in Ojców (spring No 12) can serve as good examples (Fig. 1).

6. Conclusions

1. 128 species, including 111 species of vascular plants, 14 mosses and two liverworts and one species of ferns were found in the area of 21 spring niches and two spring fens.

2. Accidental species – accidental krenophytes (KA), avoiding cold habitats and occasionally migrating from adjacent communities are the largest group (57% of the flora).

3. Meadow and forest plants comprise the largest group of spring habitats in the ONP. On the other hand, water community and spring fen plants (*Montio-Cardaminetea* class) are rare, due to the dominance of small karst springs. The species composition was formed there mostly by the impact of the immediate neighbourhood of spring niches.

4. Habitat factors such as availability of light, organic matter content, moisture content have significant influence on floristic diversity. The niche area and the degree of its damage show lower correlation.

5. Anthropogenic factors connected with transformation of spring fens that facilitate penetration of species from the immediate neighbourhood, quite often of ruderal character, have indirect influence on the floristic composition of these niches.

Acknowledgements. We would like to thank Barbara Fojcik Ph.D. from the University of Silesia in Katowice (Poland) for identification of bryophytes and consultation on this group of plants. We would also like to thank Prof. Leszek Kucharski from the University in Łódź (Poland) for his help in determining division of spring plants, according to their habitat requirements.

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Appendix 1. List of plant species recorded in the spring niches of the Ojców National Park

Name of species	Category of spring plants	Number of spring niche in ONP	Geographical element	Family
Spring fens and places, where snow lies (Class <i>Montio-Cardaminetea</i> Br.-Bl. et R.Tx. 1943)				
<i>Pellia epiphylla</i> (L.) Corda.	KO	17	CB	Pelliaceae
<i>Brachythecium rivulare</i> Schimp.	KF	1, 2, 6, 9, 11, 14, 15, 16, 17	CB	Brachytheciaceae
<i>Conocephalum conicum</i> (L.) Dumort	KI	12, 13, 15, 17, 19, 20	E	Conocephalaceae
<i>Cratoneuron filicinum</i> (Hedw.) Spruce	KO	2, 3, 5, 9, 10, 11, 12, 13, 14, 15, 18, 20	CB	Cratoneuraceae
<i>Plagiothecium laetum</i> Schimp.	KA	18, 20	CB	Plagiotheciaceae
<i>Rhizomnium punctatum</i> (Hedw.) T. J. Kop.	KF	14	CB	Cinclidaceae
<i>Cardamine amara</i> L.	KF	9	CE	Brassicaceae
<i>Chrysosplenium alternifolium</i> L.	KF	1, 5, 7, 8, 14, 15, 16, 17, 18, 19, 20	ES	Saxifragaceae
<i>Impatiens noli-tangere</i> L.	KI	1, 20	CB(d)	Balsaminaceae
Poor fens and fens (Class <i>Scheuzerio-Caricetea nigrae</i> (Nordh. 1937) R.Tx. 1937)				
<i>Agrostis canina</i> L.	KI	21	sa-ES	Poaceae
<i>Carex flava</i> L.	KF	21	CB: c-b-o	Cyperaceae
<i>Carex nigra</i> Reichard	KI	21	CB(d)	Cyperaceae
<i>Juncus articulatus</i> L. emend. K. Richt.	KF	21	CB	Juncaceae
Rushes, reeds (Class <i>Phragmitetea</i> R.Tx. et Prsg 1942)				
<i>Berula erecta</i> (Huds.) Coville	KO	4, 19	CB(d)	Brassicaceae
<i>Carex versicaria</i> L.	KF	22	CB: c-b-a	Cyperaceae
<i>Glyceria nemoralis</i> (R. Uechtr.) R. Uechtr. & Körn.	KF	20	CE-PAN-PONT	Poaceae
<i>Glyceria notata</i> Chevall.	KO	2, 4, 5, 6, 13, 20, 22, 23	sa-CE-M-IR(m)	Poaceae
<i>Scrophularia umbrosa</i> Dumort. – species reported in the '60s of the 20th century (Siedlecka-Binder 1967)	KF	21	ES(d)-IR	Scrophulariaceae
<i>Veronica anagallis-aqatica</i> L.	KF	6, 9, 11	sa-ES-M-IR	Scrophulariaceae
<i>Veronica beccabunga</i> L.	KO	6, 9, 10, 12, 20, 23	sa-ES(w)-M(n)-IR	Scrophulariaceae
Floodplain grasslands (Order <i>Trifolio fragiferae-Agrostietalia stoloniferae</i> R.Tx. 1970)				
<i>Lysimachia nummularia</i> L.	KI	1, 3, 6, 7, 8, 11, 12, 15, 17, 22, 23	sa-CE-M(n)	Primulaceae
<i>Potentilla anserina</i> L.	KI	12	CB	Rosaceae
<i>Ranunculus repens</i> L.	KI	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 20, 22, 23	sa-ES-M	Ranunculaceae
Meadows constantly and periodically wet (Order <i>Molinietales coeruleae</i> W.Koch 1926)				
<i>Alopecurus pratensis</i> L.	KI	22, 23	sa-ES	Poaceae
<i>Caltha palustris</i> L.	KF	6, 21, 22	CB	Ranunculaceae
<i>Cirsium oleraceum</i> (L.) Scop.	KI	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 20, 22, 23	ES(w)	Asteraceae
<i>Cirsium rivulare</i> (Jacq.) All.	KI	22, 23	CE(s)	Asteraceae
<i>Crepis paludosa</i> L. Moench	KI	6	CE	Asteraceae
<i>Deschampsia caespitosa</i> (L.) P. Beauv.	KA	5, 22, 23	ES-IR-Asia SE	Poaceae
<i>Equisetum palustre</i> L.	KF	12, 20, 21, 22	CB	Equisetaceae
<i>Filipendula ulmaria</i> (L.) Maxim.	KI	6, 12, 20, 23	sa-ES	Rosaceae
<i>Galium uliginosum</i> L.	KI	21, 22	sa-ES	Rubiaceae
<i>Geranium palustre</i> L.	KI	3, 12, 20, 22, 23	sa-ES	Geraniaceae
<i>Juncus effusus</i> L.	KI	3, 22	cosmop	Juncaceae
<i>Lychnis flos-cuculi</i> L.	KI	22, 23	sa-ES(w)-M(n)	Caryophyllaceae
<i>Mentha longifolia</i> (L.) L.	KF	4, 5, 6, 8, 11, 12, 13, 20, 21, 22, 23	CB	Lamiaceae
<i>Mentha spicata</i> L. emend. L.	KI	12, 22	ES-M	Lamiaceae

Name of species	Category of spring plants	Number of spring niche in ONP	Geographical element	Family
<i>Myosotis palustris</i> (L.) L. emend. Rchb.	KF	2, 3, 5, 6, 7, 11, 16, 20, 21, 22, 23	sa-ES-M(n)	Boraginaceae
<i>Sanguisorba officinalis</i> L.	KA	23	ES-IR(m)-Asia E	Rosaceae
<i>Scirpus sylvaticus</i> L.	KF	6, 12, 21, 22, 23	sa-ES(d)	Cyperaceae
Fresh meadows and pastures (Order <i>Arrhenatheretalia</i> Pawl. 1928)				
<i>Alchemilla gracilis</i> Opiz	KA	3	CE	Rosaceae
<i>Arrhenatherum elatius</i> (L.) P. Beauv. Ex J. Presl & C. Presl	KA	11, 12, 23	sa-CE-M(n)	Poaceae
<i>Dactylis glomerata</i> L.	KA	23	sa-ES(d)-M-IR	Poaceae
<i>Heracleum sphondylium</i> L.	KA	23	ES(w)	Apiaceae
<i>Taraxacum officinale</i> F. H. Wigg.	KA	4, 7, 9, 10, 13, 20	sa-ES-M-IR	Asteraceae
<i>Trifolium repens</i> L.	KA	4	sa-ES-M-IR	Fabaceae
<i>Trisetum flavescens</i> (L.) P. Beauv.	KA	23	sa-CE-M	Poaceae
Fresh and moist meadows (joint species) (Class <i>Molinio-Arrhenatheretea</i> R.Tx. 1937)				
<i>Cardamine pratensis</i> L.	KA	21	CB(w, n)	Brassicaceae
<i>Cerastium holosteoides</i> Fr. emend. Hyl.	KA	23	sa-ES-M-IR	Caryophyllaceae
<i>Festuca pratensis</i> Huds.	KA	22	sa-ES-IR(m)	Poaceae
<i>Holcus lanatus</i> L.	KA	23	sa-CE-M	Poaceae
<i>Lathyrus pratensis</i> L.	KA	12, 22, 23	sa-ES-M-IR	Fabaceae
<i>Phleum pratense</i> L.	KA	22	sa-ES-M	Poaceae
<i>Poa pratensis</i> L.	KA	22	CB	Poaceae
<i>Poa trivialis</i> L.	KA	23	sa-ES-M(?) IR(?)	Poaceae
<i>Ranunculus acris</i> L.	KA	23	sa-ES(w)-M(n)	Ranunculaceae
<i>Rumex acetosa</i> L.	KA	6, 7, 22, 23	ES	Polygonaceae
Nitrophilous clippings and ruderal places (Class <i>Epilobietea angustifolii</i> R.Tx. et Prsg 1950)				
<i>Fragaria vesca</i> L.	KA	13	CB	Rosaceae
<i>Sambucus nigra</i> L.	KA	4, 18	sa-CE-M	Caprifoliaceae
Thermophilous thickets (Class <i>Rhamno-Prunetea</i> Rivas Goday et Garb. 1961)				
<i>Cornus sanguinea</i> L.	KA	12	sa-CE-M	Cornaceae
<i>Prunus spinosa</i> L.	KA	4	sa-CE-M-IR(w)	Rosaceae
Moist riparian forests (Alliance <i>Alno-Ulmion</i> Br.-Bl. et R.Tx. 1943)				
<i>Plagiomnium undulatum</i> (Hedw.) T. J. Kop.	KI	6, 7, 8, 12, 13, 15, 20	CE	Plagiomniaceae
<i>Festuca gigantea</i> (L.) Vill.	KA	6, 9	sa-ES(w)-IR(m)	Poaceae
<i>Geranium phaeum</i> L.	KA	12, 15, 16, 19, 23	CE: a-ce	Geraniaceae
<i>Padus avium</i> Mill.	KI	18, 20	ES	Rosaceae
<i>Stellaria nemorum</i> L.	KA	1, 3, 5, 19, 20	CE-M(n)	Caryophyllaceae
Deciduous forests (with different humidity) (Class <i>Quercio-Fagetea</i> Br.-Bl. et Vlieg 1937)				
<i>Atrichum undulatum</i> Web. et Mohr.	KA	14, 18	CB	Polytrichaceae
<i>Dryopteris filix-mas</i> (L.) Schott	KA	18	CB(d)	Dryopteridaceae
<i>Acer platanoides</i> L.	KA	13	CE-M(m)	Aceraceae
<i>Acer pseudoplatanus</i> L.	KA	13, 17, 20	CE-M(m)	Aceraceae
<i>Aegopodium podagraria</i> L.	KA	1, 4, 6, 7, 12, 13, 14, 15, 16, 19, 20, 23	sa-ES(w)	Apiaceae
<i>Asarum europaeum</i> L.	KA	13	CE-M(n)	Aristolochiaceae
<i>Campanula trachelium</i> L.	KA	13	sa-ES(w)-M	Campanulaceae
<i>Carex sylvatica</i> Huds.	KA	7, 10, 13, 15, 16, 17	sa-CE-M(n)	Cyperaceae
<i>Carpinus betulus</i> L.	KA	13	CE-M(n)	Corylaceae
<i>Corylus avellana</i> L.	KA	4	sa-CE-M(n)- IR(w)	Corylaceae
<i>Epipactis helleborine</i> (L.) Crantz	KA	13	sa-ES-M-IR	Orchidaceae
<i>Fagus sylvatica</i> L.	KA	18	sa-CE(w): ce-b	Fagaceae

Name of species	Category of spring plants	Number of spring niche in ONP	Geographical element	Family
<i>Fraxinus excelsior</i> L.	KA	1, 17	sa-CE-M(n)-IR(w)	Oleaceae
<i>Galeobdolon luteum</i> Huds.	KA	14	CE: ece	Lamiaceae
<i>Lonicera xylosteum</i> L.	KA	13	ES(w)	Caprifoliaceae
<i>Poa nemoralis</i> L.	KA	2, 13, 18, 19	sa-ES-M-IR	Poaceae
<i>Primula elatior</i> (L.) Hill.	KA	14, 15, 20, 23	CE	Primulaceae
<i>Pulmonaria obscura</i> Dumort.	KA	1, 13, 14, 15	CE	Boraginaceae
<i>Stellaria holostea</i> L.	KA	14, 15	sa-ES(w)-M(n, e)	Caryophyllaceae
<i>Ulmus glabra</i> Huds.	KA	17	sa-CE-M(n)	Ulmaceae
<i>Viola reichenbachiana</i> Jord. ex Boreau	KA	17	CE(w)-M(n)	Violaceae
Coniferous forests and woods (with different humidity) (Class <i>Vaccinio-Piceetea</i> Br.-Bl. 1939)				
<i>Pleurozium schreberi</i> (Willd. ex Brid.) Mitt.	KA	15	CB	Hylocomiaceae
<i>Oxalis acetosella</i> L.	KA	13, 14, 15, 17	sa-ES	Oxalidaceae
Moist, ruderal and nitrophilous places (Class <i>Artemisietea vulgaris</i>)				
<i>Alchemilla glabra</i> Neygenf.	KA	22, 23	CE: a-ne	Rosaceae
<i>Chaerophyllum aromaticum</i> L.	KI	4, 8, 10, 15, 16, 18, 20, 23	CE: ece	Apiaceae
<i>Epilobium hirsutum</i> L.	KF	12	sa-ES(w)-M-IR	Oenotheraceae
<i>Epilobium parviflorum</i> Schreb. – species reported in the '60s of the 20th century (Siedlecka-Binder 1967)	KF	13	sa-CE-M-IR(w)	Oenotheraceae
<i>Epilobium roseum</i> Schreb.	KF	7, 9, 11, 12, 22	sa-ES(w)	Oenotheraceae
<i>Galium aparine</i> L.	KA	3, 12, 20, 23	CB(d)	Rubiaceae
<i>Geranium robertianum</i> L.	KA	5	sa-CE-M-IR	Geraniaceae
<i>Geum urbanum</i> L.	KA	1, 4, 6, 8, 14, 15, 16, 17, 18	sa-ES(w)-M-IR(m)	Rosaceae
<i>Glechoma hederacea</i> L.	KA	16	sa-ES-M(n, w)	Lamiaceae
<i>Impatiens parviflora</i> DC.	KA	4, 14, 15, 19, 20	AT (native)	Balsaminaceae
<i>Lamium maculatum</i> L.	KA	19	CE-M(n)	Lamiaceae
<i>Petasites hybridus</i> (L.) P. Gaertn., B. Mey. & Scherb.	KI	10	CE-M(n)	Asteraceae
<i>Rumex obtusifolius</i> L.	KA	3, 4, 6, 7, 10, 11, 12, 20, 22, 23	sa-CE-M(n)-IR(w)	Polygonaceae
<i>Urtica dioica</i> L.	KI	3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 19, 20, 23	ES-M-IR-Asia E	Urticaceae
Weeds of cultivated fields and ruderal places (Class <i>Stellarietea mediae</i> R.Tx., Lohm. et Prsg. 1950)				
<i>Lapsana communis</i> L.	KA	18	sa-CE-M(n)	Asteraceae
<i>Stellaria media</i> (L.) Vill.	KA	3, 20, 23	cosmop	Caryophyllaceae
<i>Tusilago farfara</i> L.	KA	3, 20	sa-ES(w)-M(n)-IR	Asteraceae
other habitats (with different humidity)				
<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen	KA	18	CB	Brachytheciaceae
<i>Brachythecium rutabulum</i> (Hedw.) Schimp.	KI	3, 8, 14, 15, 17, 20	E	Brachytheciaceae
<i>Dichodontium pellucidum</i> (Hedw.) Schimp.	KF	20	CB	Dicranaceae
<i>Didymodon rigidulus</i> Hedw.	KA	2	CB	Pottiaceae
<i>Fissidens taxifolius</i> Hedw.	KA	17	E	Fissidentaceae
<i>Fontinalis antipyretica</i> Hedw. – species reported in the 1960's (Siedlecka-Binder 1967)	KF	13	CB	Fontinalaceae
<i>Plagiothecium denticulatum</i> (Hedw.) Schimp.	KI	18	CB	Plagiotheciaceae
<i>Aconitum moldavicum</i> Hacq.	KI	1, 15	CE: ct	Ranunculaceae
<i>Agrostis capillaris</i> L.	KA	22, 23	sa-ES-M(n)	Poaceae
<i>Ajuga reptans</i> L.	KA	4, 19, 20	sa-CE-M(n)	Lamiaceae
<i>Alchemilla crinita</i> Buser	KA	23	CE: a-ce	Rosaceae
<i>Chaerophyllum hirsutum</i> L.	KI	3, 6, 7, 8, 11, 12, 13, 20, 23	CE: a-ce	Apiaceae
<i>Equisetum arvense</i> L.	KA	20	CB	Equisetaceae
<i>Equisetum sylvaticum</i> L.	KI	22	CB	Equisetaceae

Name of species	Category of spring plants	Number of spring niche in ONP	Geographical element	Family
<i>Geum rivale</i> L. – species reported earlier by Soltys (2005)	KI	6	CB(d)	Rosaceae
<i>Hedera helix</i> L.	KA	1	sa-CE(w)-M	Araliaceae
<i>Lolium perenne</i> L.	KA	4	sa-CE-M-IR(w)	Poaceae
<i>Mentha aquatica</i> L. – species reported in the 1960s (Siedlecka-Binder 1967)	KF	13	sa-ES(w)-M	Lamiaceae
<i>Mycelis muralis</i> (L.) Dumort.	KA	13	CE	Asteraceae
<i>Pimpinella saxifraga</i> L.	KA	23	sa-ES(w)-M(n)	Apiaceae
<i>Poa annua</i> L.	KA	9	sa-ES-M-IR-Asia E	Poaceae
<i>Veronica chamaedrys</i> L.	KA	3, 6, 7, 10, 11	sa-ES-M(n)	Scrophulariaceae

Explanations: category of spring plants, KO – obligatory krenophytes, KF – facultative krenophytes, KI – indifferent krenophytes, KA – accidental krenophytes; geographical element (according Hill *et al.* 2007 and Zając & Zając 2009), AT – Asian Temperate (native range), CB – Circum-Boreal sub-element, CB: c-b-o – Circum-Boreal-Oceanic group, CB: c-b-a – Circum-Boreal-Arctic group, E – European element, ES – Euro-Siberian sub-element, CE – European-temperate sub-element, CE: ece – East-European distributional type, CE: ce-b – European-temperate Balkan distributional type, CE: a-ce – Alpine-Central-European distributional type, CE: a-ne – Alpine-North-European distributional type, CE: ct – Carpathian distributional type, H – Holarctic element, IR – Irano-Turanian element, M – Mediterranean element, PAN-PONT – Pontic-Pannonian sub-element, cosmop – Cosmopolitan element; additional designations, d – disjunctive range, e – eastern, m – in a mountain regions, n – northern, s – southern, sa – extension in the beginning of diagnosis to the Atlantic region of Europe, w – western, ? – doubtful to a diagnosis of the part of element